Part I.

ON THE [illegible] OF [illegible] SPECTRUM LINES.

ON THE ANALYSIS OF BRIGHT SPECTRUM LINES.

It is well-known that a change is produced in the wave-length and distribution of light in the lines of the spectrum ofmetallic vapours and gases when different external conditions are introduced. In most cases these changes were first observed and measured by means of the Rowland grating. Recently, however, these effects have become more readily observable through interference methods, in which the interference-bands are produced with large differences in the paths of the rays.

*Michelson, by aid of his interferometer, resolved the important lines in the radiations of some vapours and gases rendered luminous in vacuum-tubes, and he has studied these radiations in a magnetic field. With his echelon spectroscope he has investigated the same subjects. **Fabry and Perot with their interferometer have investigated the radiations from vapours in the electric arc and in vacuum-

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* Phil. Mag. (5) 31, 338, 1891; 34, 280, 1892.

** Ann de Chim et Phys. 16, [illegible], 1899; [illegible]. Astrophys. Journ. 9, [illegible], 1899.

tubes, and have applied their method for an exact determination of the wave-lengths of some of the lines in the spectrum of the iron arc and of the dark lines in the sun's spectrum. *Lummer also by an interference method has studied the same radiations, particularly those from mercury, and has separated its prominent lines into many components.

When one compares the results of these investigations the agreement is not very satisfactory. Not only do the number and intensity of the components differ, but the distances between the components do not agree.

The work presented in this paper was undertaken at the suggestion of Professor Ames. The objects of the work were; to study interferometer methods; to obtain, if possible, more consistent results as to the constitution of the lines; and to determine the changes produced in the components under various conditions. Michelson remarks in one of the papers cited, "Still, in many cases, the range of visibility due to slight variations in the conditions shows that the behaviour of each substance must be carefully studied under all possible circumstances of temperature, pressure, strength of current, size and shape of electrodes, diameter of vacuum-tube, etc."

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* Verhandl. d. D. Phys. Ges. 3, [illegible], 1901.
Phys. Zeit., (3), [illegible], 17[illegible], 190[illegible].

After experimenting a few months with both the Michelson and the Fabry and Perot interferometer the author was fully convinced that the Fabry and Perot method possessed the advantage for the problems in view, since it shows directly the structure of a given radiation by the simple inspection of the system of fringes. Each fringe is in fact a true spectrum of the source and the conditions are the same as those existing in the spectra obtained by the use of a grating having a small number of lines but where the spectra employed are of a very high order. During the progress of the experiments the method proposed by Lummer appeared. While I have not been able to use this method exactly, I used, before I read his paper, one which is very similar to it. This method and results obtained will be described below.

METHOD.

The method involved in this production of interference-fringes will be first briefly considered as it will assist towards a clear conception of the results.

Consider a ray of monochromatic light incident at an angle θ upon two glass plates whose inside surfaces A and Fig. 1, are slightly silvered and separated from one another a distance D. If the silvered surfaces are parallel, we have

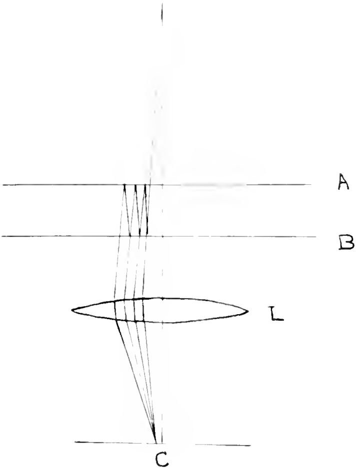

Fig. 1.

be subject to multiple reflections a number of transmitted rays coming from the same source, whose differences of path increase in arithmetical progression. The differences of path with respect to the first are 2D cos θ, 4D cos θ, ... 2 n D cos θ. By means of a lens L these rays are brought to a focus in its focal plane, producing there an interference pattern, bright and dark bands according as 2 D cos θ, 4 D cos θ, etc. are equal to an even or an odd number of half wave-lengths. If we have a symmetrical cone of rays incident upon the plates, the system of fringes obtained on a screen placed in the focal plane of the lens will be concentric circles, having as their centre the point of intersection of the normal from the source upon the plates with the screen, in the figure. The radii of these circles are equal to f tan θ, where f is the focal length of the lens L.

The intensity of the light at different points in the interference pattern was first worked out by Airy*. His formula is

$$I = \frac{I_0 (1 - b^2)^2}{(1 - b^2)^2 + 4 b^2 \sin^2 (\frac{\pi \Delta}{\lambda})},$$

where I_0 is the intensity of the incident light transmitted

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* Phil. Mag. (3) 2, 20, 1833.

[illegible] Δ the difference [illegible]
rays. We see from this formula that for a given value of b, I will have a maximum when $\frac{2\Delta}{\lambda}$ is an even integer and a minimum when $\frac{2\Delta}{\lambda}$ is an odd integer. Hence the intensity of the bright fringes is I_0, while that of the dark fringes is $I_0\left(\frac{1-b^2}{1+b^2}\right)^2$.

Fabry and Perot have calculated the values of I for different values of b and have plotted curves showing the relation between I and Δ for these values of b. The greater the value of b the steeper becomes the intensity curve, so that the interference pattern consists of bright fringes which are very narrow compared with the dark ones (see Plate 1, fig. 1). As we shall see later, the sharper and finer these bright bands are the easier are the radiation analysed and the components measured, thus, while on this account it is advantageous to have b very large by increasing the thickness of the silver film, it must not be so large that I_0, the intensity of the light transmitted, is too small.

Let us now consider the light which is incident upon the plates not to be monochromatic, but to consist of two wave-lengths λ and $\lambda + d\lambda$, [illegible] screen [illegible] focal [illegible] will be covered with two sets of concentric rings. [illegible]

[illegible] in [illegible] of [illegible] the

n [illegible] ence, then we [illegible] the [illegible]

$$\frac{\Delta}{\lambda} = \frac{\Delta}{\lambda + d\lambda} + n,$$

where n is any whole number, or

$$d\lambda = \frac{n\lambda^2}{\Delta - n\lambda}.$$

Since Δ is always large relative to $n\lambda$ we may write

$$d\lambda = \frac{n\lambda^2}{\Delta} = \frac{n\lambda^2}{2t\cos\theta}.$$

Then by observing the first coincidence of the rings ($n = 1$) near the centre of the system where θ is so small that we may consider $\cos\theta = 1$, knowing the value of λ, and [illegible], the value of $d\lambda$ can be determined with a very [illegible] accuracy. When $d\lambda$ is very small it is not necessary for the determination of its value to separate the plates until the first coincidence occurs, but only till the separation of the rings is clearly visible. When the separation of the systems of rings is, say, one [illegible] of the distance between consecutive rings of the same radiation, the equation becomes

$$d\lambda = \frac{\lambda^2}{\text{[illegible]}\,t}.$$

The resolving power of this method depends upon the distance between the plates and also upon the [illegible] of the lines. The [illegible] near the [illegible]

t[illegible] resolution [illegible]. It [illegible] advantageous [illegible] observations upon the central fringe [illegible] because their separation [illegible] greatest. This can be shown if we consider the lengths of the radii of the rings. With the centre of the system a bright ring

$$\Delta = 2D = m\lambda ,$$

where m is an integer; for the first bright fringe out from the centre the difference of path is

$$2D \cos\theta = (m - 1)\lambda ,$$

hence, $\tan\theta = \dfrac{\sqrt{2m-1}}{m-1}$

and the radius R_1 of the ring is given by the expression

$$R_1 = f \tan\theta = f\,\frac{\sqrt{2m-1}}{m-1}$$

Similarly for the second bright fringe

$$2D \cos\theta = (m - 2)\lambda$$

hence, $$R_2 = f\,\frac{\sqrt{4m-4}}{m-2}$$

and so forth for R_3, R_4, etc.

The following table gives the values of R_1/f, R_2/f [illegible] for different values of m.

m	R_1/f	R_2/f	R_3/f	R_4/f	R_5/f
1	∞				
2	1.73[illegible]	∞			
3	1.11[illegible]	[illegible]	∞		
4	[illegible]	1.[illegible]	[illegible]	∞	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

From this table we see that when $m = 1$, i. e., the difference of path is one wave-length, there is only one interference-band and its radius is infinite, thus the field would be uniformly illuminated. When the difference of path is two wave-lengths there are only two fringes, the first whose radius is 1.732 f, the radius of the second being infinite. For $m = 3$ there are three fringes. The entire system of bands could only be observed by means of infinite glass plates. We also see that as m gets large, which in practice is generally the case, the lower row in the table shows us that the distance between the first and second ring is much larger than that between the second and third and so on moving out in the system. Thus the separation of the fringes gradually diminishes as we go out from the centre, and hence the advantage of making the observations on the central fringes. This is clearly shown by the figures on the plates which are reproduced from photographs.

This interference method, besides being applied for the analysis of spectrum lines, can be used in the study of the changes in the wave-length of any radiation under the different conditions as indicated above. Any small change will be shown by an increase or decrease in the diameters of these rings, and since very clear photographs can be taken, very accurate measurements on the changes produced can be obtained.

APPARATUS.

After experimenting some time with an instrument which seemed to be particularly sensitive to vibrations, even when every precaution was taken to eliminate extraneous disturbances, a new instrument was constructed. In the construction of this instrument the essential parts sought after were, that the mountings for the plates should be rigid and placed on a massive base so that the bands should be perfectly steady, and that the movable carriage carrying one plate should be capable of very slow uniform motion always remaining parallel to its original position, enabling one to follow clearly the change from one band to another.

In working with a Michelson interferometer as made by Gaertner & Co. the fringes obtained were very steady, even when the instrument rested on a table in the laboratory. I took this instrument stripped it of its mirrors and plates, and using the base, carriage, and screw constructed the apparatus employed.

The apparatus consists of two plane glass plates 5.3 cms. by 2.5 cms. and about .6cm. thick, each slightly prismatic in shape; the two faces making with one another an angle between 1" and 2". This prevents the interference bands formed in the plates themselves being superimposed upon those under

observation. Both plates are rigidly mounted in brass frames. One frame can be moved about a vertical axis and the other about a horizontal axis. For very small motions about these axes, so that the silvered surfaces may be made perfectly parallel, two glass tubes were bent into convenient shapes and clamped to the instrument. Their ends resting against a frame are covered with thin sheet rubber. To the other ends are attached long rubber tubes and these connected with a support. By carefully raising or lowering these tubes, which are filled with mercury, the pressure against the frame being therefore varied, very small rotations around either axis are obtained and the surfaces thereby placed in perfect adjustment. Fabry and Perot employed this method using water in their tubes instead of mercury. The carriage containing one of the frames rests upon steel ways, very accurately ground, and is connected by means of a small carriage, placed underneath, to a screw of 1 mm. pitch. The force being thus applied to the carriage in a direction parallel to the motion produces no rocking, as is shown by the fact that the fringes always remained in adjustment during the motion.

To turn the screw two handles are on the instrument, one for rapid and the other for slow motion. A turn of the first corresponds to one turn of the screw. The other is a tangent screw by which it is possible to give the carriage such a

slow motion that the change from one fringe to the next can be easily followed. To both handles were attached graduated discs enabling the distance between the plates to be accurately known.

The whole instrument weighed over 15 kilograms and was placed on a brick pier. The greater part of the observations were taken at night. With this instrument the fringes were always perfectly steady and very long photographic exposures could be made without the least fear of obtaining a blurred image.

Since the radiations from all the sources studied consisted of many wave-lengths it was necessary to employ some arrangement by which the wave-length under consideration could be separated from the others. The following, Fig. 3, was the plan first adopted. S is the source of light. The radiation undergoes an analysis by a Steinheil spectroscope consisting of two flint-glass prisms. The lens L brings the different wave-lengths to a focus on a screen I, which contains a slit. Through this slit the wave-length considered is allowed to pass and passing between the silvered plates forms the interference bands, which are observed by a telescope T or photographed.

The photographic apparatus consisted of a long light-proof box with a circular hole cut in one side. The eyepiece

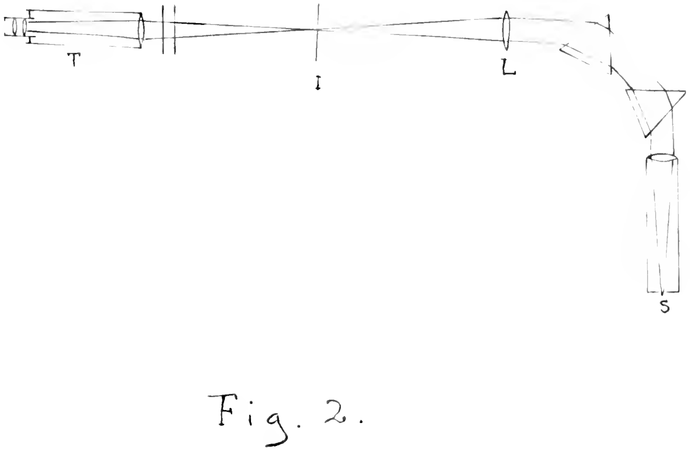

Fig. 2.

of [illegible] telescope being removed, the [illegible] was placed so that [illegible] opening fitted over the end of the telescope. The photographic plate 13 by 3 cms. was in the focus of the objective and mounted so that it could be slid past the opening, and hence a number of exposures made upon one plate.

With the silvered plates illuminated in this way, with divergent light, the entire rings of the interference-bands are observed in the focal plane of the objective as shown on Plate I, fig. 1. The following method, however, was found to be better for the analysis of the radiations. The lens L was removed and the interferometer placed directly behind the prisms so that the parallel light fell upon the silvered plates. With a broad slit in the spectroscope we have in the telescope, focussed for infinity, broad lines corresponding to the lines in the spectrum. These lines are crossed with the interference-bands produced by the plates. By this means the light has been concentrated into a few interference-bands and on this account many of the weaker components appear which cannot be seen with the light divergent as above. Fig. Plate I [illegible] [illegible] clearly. This photograph is of the [illegible] radiation and [illegible] components when the interference-plates are separated 3 [illegible].

[illegible]. The [illegible] of [illegible] we [illegible] of the telescope at the same time a number of lines [illegible] different kinds of interference-bands depending upon the constitution of the radiation making up each line. This facilitates greatly the analysis of the radiations and we see at once any change that may take place in one or all of the lines through any change of external conditions. The dispersion of the prisms and the magnification of the telescope were such that about half of the spectrum was visible at once. Plate I, figs. 3, 4 and 5 each show the interference-bands due to the two yellow and green lines of mercury vapour taken at the same time with the plates separated at different distances. On account of the broad slit the yellow lines passed through the interference-plates together and hence their interference-bands are superimposed upon one another. The other lines in this region of the spectrum of mercury being of less intensity do not show in the photographs, which were exposed only long enough to get the clearest pictures of the lines considered. The dark green line was quite visible to the eye after passing through the silvered plates. The curvature of the bands in the different lines is of course due to the amount of separation of the plates and to the angle of incidence with [illegible]

[illegible] ...tions are independent upon the interferometer-plates.

For the determination of the scale-reading corresponding to the place where the silvered plates were in contact, a method [illegible] or incandescent sodium vapour in a vacuum-tube was employed. The slit of the spectroscope being wide the two D lines were superimposed so that the two radiations together entered the interferometer. The plates were separated until the first coincidence happened, and the readings taken; the operation was repeated several times. Since the difference, d λ, between the sodium lines is known with accuracy from Rowland's tables the distance D between the plates can be calculated from the above equation and thus the zero point obtained. Readings were taken of the successive coincidences as the plates were separated and in this manner the screw was calibrated. If a more accurate calibration is required the two yellow lines of mercury can be used; since their distance apart is about three times that of the D lines, the coincidences occur three times more often in a given distance.

Remarks on Interference-bands.

Before considering the results I will add some remarks concerning the [illegible] of the interference-[illegible] [illegible] interferometer [illegible].

When the silvered surfaces are not parallel, but are inclined to one another at a small angle, the fringes obtained are localised in the plates and, as is well known, can be seen by the eye or with a lens focussed on the plates. These fringes, however, can only be obtained when the separation of the plates is very small.

In order to procure clear interference-bands with great differences of paths it is necessary to have the surfaces rigidly parallel. The fringes in this case are seen by the eye, or by means of a telescope focussed for infinity. One of the most important results of this work is that the silvered faces of the plates must be perfectly parallel and the telescope must be focussed for finity to obtain correct results. While this has been noted by former investigators I wish to strongly emphasize the necessity for these adjustments for if these two conditions are not fulfilled all manner of anomalous results may be expected.

On Plate I are shown some photographs of some of the results obtained, if these conditions are not obeyed. Figs. 6 - 12 were all taken with the bright green line of incandescent mercury vapour in a vacuum-tube. None of the photographs are magnified, the focal length of the objective used was about 1 [illegible].

The separation of the interference-plates in figs. 1, 6 and 7 was 3 mms. In 1, where the adjustments are perfect, 6 and 7 show the effect upon the bands when the interference-plates are only a very small degree from being parallel, they being displaced from parallelism by merely raising one of the mercury adjusting tubes less than a centimetre.

In figs. 8 and 9 the plates are separated 0.5 mm., in neither case are the plates parallel, in 8 they have an angular separation of over 1". These photographs also show the interference-bands produced <u>in</u> the plates themselves superimposed upon the other.

It is an advantage in the observations to obtain all the light possible, thus a broad source is always employed. The interfering rays from the different points of the source can only produce a clear interference pattern in the focal plane of the objective; in any other plane the bright interference-bands will be wide and hazy. Figs. 10, 11, and 12, illustrate this point. The whole slit is covered with the exception of two points separated 4 mms. from one another in a horizontal direction. Fig. 10 shows the effect when the photographic plate is placed about 1 cm. inside the focus of the objective. Fig. 11 when the plate is placed 1 cm. beyond the focus. Fig. 12 when the plate is exactly in the focal plane, then the [illegible]

pr[illegible] al [illegible] of [illegible] are [illegible] together [illegible] [illegible] interference-rings. [illegible] [illegible] 10 [illegible] [illegible] [illegible], [illegible] 10 and 11 would be wide and hazy, [illegible] if [illegible] [illegible] due to the [illegible] of the radiation were present [illegible] would probably be entirely obliterated.

To set the telescope at infinity is easy, [illegible] adjustments necessary to bring the silvered surfaces parallel are more or less difficult [illegible] only be obtained with practice. The plates are parallel when the fringes are sharp and the illumination equally distributed over the [illegible] [illegible] rings due to the components.

A REFLECTING INTERFEROMETER.

In the Fabry and Perot interferometer [illegible] [illegible] [illegible] is lost due to reflection from the surface of the silvering in contact with plate A, Fig. 1, so that only a [illegible] percentage is transmitted. To eliminate this defect [illegible] lates were mounted [illegible] the following [illegible]. [illegible] A was heavily silvered [illegible] [illegible] [illegible] and [illegible] carriage of the interferometer [illegible] described above. [illegible] its double [illegible] [illegible] silvered, [illegible] reflecting [illegible] [illegible] [illegible] e. [illegible] A [illegible]

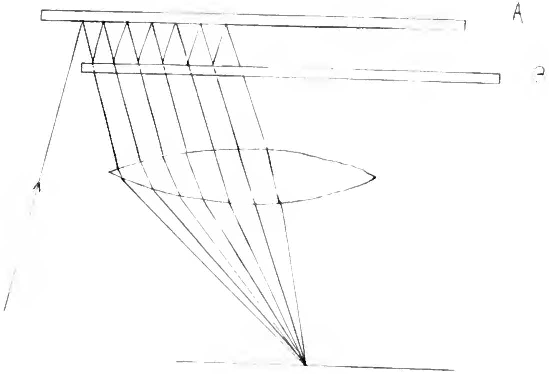

Fig 3.

RESULTS.

On the basis of what has preceded the following results have been obtained. A number of sources were employed, - metallic vapours in vacuum-tubes rendered luminous by the discharge from a large induction-coil, metallic vapours in a Bunsen flame and in an electric arc, and lastly the electric spark between electrodes of the metals. This latter source was found to be very unsatisfactory. Of the many sources tried the bright radiation from mercury vapour was the best for obtaining observations on the changes produced in the compounds by external changes in the conditions. We will thus first consider the results with this source. Great pains were always taken to have perfect adjustments chiefly with respect to the focussing of the telescope and the parallelism of the interference-plates, before any readings were taken.

The vacuum-tube discharge was obtained in a Geissler tube with mercury electrodes of the form suggested by Runge and Paschen*, the capillary of which was placed directly in front of the slit of the spectroscope. The different tubes were connected to a Geryk pump and a pressure gauge, enabling the pressure of the vapour through [illegible] -

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* Astrophys. Journ. [illegible], [illegible], [illegible].

[illegible] are [illegible] to [illegible] quickly [illegible] from a few millimetres to a fraction of a millimetre.

It is rather difficult to decide what is the most advantageous way to record results, whether to take what appears to be the centre of gravity of the various components constituting the radiation as the position from which to measure wave-lengths, which is the usual way in the measurements of the lines obtained by means of the grating, or to consider the component of the greatest intensity as the standard and record the wave lengths of the other components with reference to this; this method is the one employed by Michelson, and Fabry and Perot. The latter method, nevertheless, is unsatisfactory, for I have found, even in some of the few radiations investigated, that there are two or more bright components whose intensities are equal. For want of a satisfactory standard, and also that the following results may be easily compared with those of the other investigators, their method has, however, been followed. In the cases where the brightest components are of equal intensity one of them has been selected for the standard. In what follows the plus sign indicates that the component has a longer wave-length than the standard, the minus sign the reverse.

The following results were [illegible] after a [illegible] of observations with [illegible]

[illegible] and t[illegible] of 1.5 [illegible]. [illegible] re[illegible] radiation [illegible] wave-l[illegible]t[illegible] components; the two brightest having about equal intensities, the one having the longer wave-lengths will be considered standard. The other components have the following differences in wave-length and in intensity relative to the one selected.

1.	Standard Component,	Intensity	1
2.	$- 1.1 \times 10^{-9}$ cm.,	"	3/4
3.	$- .9$ "	"	1/4
4.	$- 0.4$ "	"	1
5.	$+ 0.1$ "	"	1/8
6.	$+ 0.4$ "	"	1/4

Thus there are three components on the side toward the shorter wave-lengths and two towards the larger.

The violet line, 4358, is a triple having slight components on each side of the principal.

1.	Standard Component,	Intensity	1.
2.	$- 0.5 \times 10^{-9}$ cm.,	"	1/4
3.	+ 0.[illegible] "	"	1/4

Both the yellow lines have numerous components but they are of very slight intensity so that concordant results were not obtainable.

When a small amount of air was allowed to enter the vacuum-tube till the pressure was about 5 mms. the [illegible] of small intensity completely disappeared, the fringes due to the brighter components broadened and their edges became less sharply defined, showing that the atomic vibrations were not so uniform and simple as before. The same effect was noticed with the radiation from a vacuum-tube which had been used some time without any change of pressure. In the case where the pressure is changed through the introduction of air the molecular collisions may be made more frequent, which would naturally interfere with the free vibrations of the atomic systems and so produce a broadening of the bands and cause the less intense fringes to disappear. In the case of an old tube, when the pressure has not changed, there seems to be no other explanation for the observations than that the mercury vapour had become contaminated with gases driven off from the glass by the heat developed in the discharge.

Whether the atomic vibrations in a source are changed on account of the presence of molecules of foreign matter is an open question. Michelson* thinks that the presence of other molecules does not have any appreciable effect except to diminish the visibility. In the case of mercury he ob-

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* Phil. Mag. 34, [illegible], [illegible].

tained quite different visibility curves when the pressure was high to that obtained when the pressure was low. When the mercury was placed in an atmosphere of hydrogen the characteristics of the visibility curves were not changed. My results show, however, that when mercury is placed in the presence of air both in the vacuum-tube discharge and in the arc, which will be described later, the appearance of the interference-bands is clearly changed, which can only be due to a change in the oscillations of the atomic systems. Schuster in a lecture at the Royal Institution in 1881 drew from his results the conclusion " Placing a molecule in an atmosphere of a different nature - without change of temperature - produces the same effect as would be observed in lowering the temperature". In a note to the Astrophysical Journal* he says "Something similar seems to take place as regards pressure for the sodium lines may be obtained wide or narrow according as the atmosphere producing the pressure consists of sodium molecules only or of molecules of a different nature". The results here obtained seem to corroborate those of Schuster.

As being of some importance in this subject I have

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* Astrophys. Journ. 3, 292, 1896.

[illegible]roduced fi[illegible]. 14 [illegible] 15, Plate [illegible], show[illegible] t[illegible] [illegible]r[illegible]d [illegible] of the sodium lines, separated and superimposed, obtained with a sodium flame in air as the source. With sodium in a vacuum-tube these bands are as sharp as those of the mercury fringes on Plate I. Fig. 13 was obtained with the green radiation from mercury in a tube which had been used a considerable time. The separation of the plates was 6 mms. Here not even one component is visible. A comparison of this photograph with that of Fabry and Perot reproduced in the Astrophysical Journal, May, 1901 may interest the reader. This reproduction is of the fringes of the same line with the same separation of plates but shows the components. The figs. 13, 14, 15, Plate II have been magnified about five times. Fig. 16 has not been magnified, and shows how sharp the bands are when the plates are separated 1 cm. Here also the components of the mercury green radiation are invisible.

With tubes containing capillaries whose diameters are greater than 2 mms. the light obtained with an ordinary discharge is not sufficiently intense to show the finer components. The components that can be seen have their edges quite sharp, showing that the vibrations in these tubes are probably the same as in the tubes of smaller capillaries. The finer the capillary the greater the electrical resistance to the discharge and hence a rise in temperature, causing a

of outer light. Temperature is an important factor, for on heating only the capillary of the tube where there is no liquid mercury present and thus producing no noticeable change in the pressure in the vacuum tube, the kinetic energy of [illegible] [illegible] motions is increased such that many of the components of small intensity invisible before are now very readily seen.

The number and intensity of the components were the same whether the tube was placed "side on" or "end on", that is whether the discharge was perpendicular or parallel to the propagation of the light through the slit.

The introduction of capacity in parallel with the discharge circuit had an interesting effect. With three large Leyden jars, each gallon jars, the fringes were broadened and the finer components disappeared. The effect appeared in every way analogous to that when the pressure was increased.

The next step was to investigate the radiations from a mercury arc and compare the results with those above. After many trials with different kinds of arcs the following form, Fig. 1, was found to be most satisfactory. The arc is between two mercury surfaces. [illegible] ordinary glass reservoir of about [illegible] 60 cc. capacity. Over the [illegible] B is [illegible] of plate-glass; through the [illegible] stopper C is [illegible]

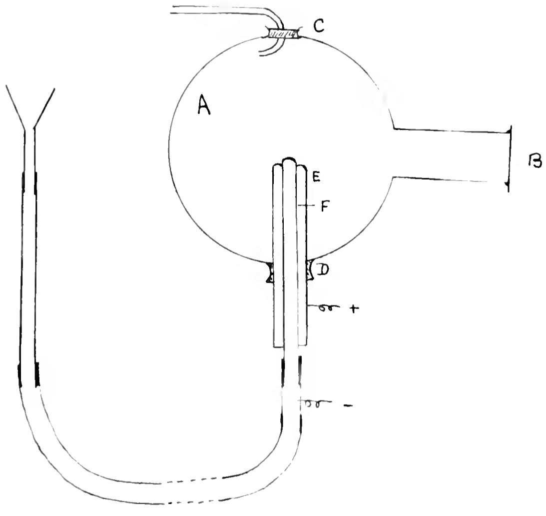

Fig 4.

the [illegible] Heryk [illegible]. [illegible] is placed [illegible] in the E of diameter 15 mm., and [illegible] of the [illegible] is placed [illegible] porcelain tube of diameter [illegible] mm. This porcelain tube is connected with a glass tube which in turn is connected with a large rubber tube. The [illegible] fills the space between the porcelain and iron tubes as well as the porcelain, glass, and rubber tubes attached. The electric poles are placed as shown in the figure. By raising the barometer column until a drop of mercury flows over into E the arc is started. Any further adjustments are easily carried out by raising or lowering the mercury column. Since all the joints were made air-tight the pressure could be varied by means of the pump. Within a few seconds after the arc is started the whole bulb of receiver is covered with a layer of mercury thrown off from the arc, this does not penetrate into the neck so that the glass at [illegible] is always clear and the radiation from the arc passes through to the slit of the spectroscope without loss. The whole apparatus [illegible] placed in a cold water bath to keep the joints cool. This was found unnecessary with the apparatus used even when the arc was steadily run [illegible] ten minutes. [illegible] 1[illegible] volts were employed, the current was varied by means of a rheostat, generally [illegible] res were used.

With [illegible] pressure [illegible] the results were [illegible] same as those obtained with vacuum-tubes as given above. However at this pressure it was very difficult to obtain any components and the bands were broad and hazy. This is probably due, as above, to pressure and the presence of a number of molecules of air.

The results obtained with the other metallic vapours and gases are briefly as follows.

<u>Cadmium</u>. Small pieces of metallic cadmium were enclosed in a Geissler tube surrounded by an asbestos jacket; when heated with a Bunsen flame the metal easily vapourized.

The red line 6439 is nearly monochromatic; there is, however, a weak component towards the shorter wave-lengths.

1.	Standard Component,	Intensity	1
2.	$- 0.1 \times 10^{-8}$ mm.,	"	1/5

The green line 5086 is composed of four components the three weaker being on the side towards the larger wave-lengths.

1.	Standard Component,	Intensity	1.
2.	$+ 0.4 \times 10^{-8}$ mm.,	"	1/4
3.	$+ 0.25$ "	"	1/4
4.	$+ 0.1$ "	"	1/8

The blue line 4800 has a component on each side of the

rincipal.

1. Standard Component, Intensity 1.

2. $+0.6 \times 10^{-8}$ mm., " 1/3

3. -0.4 " " 1/4

Thallium. A piece of metallic thallium was placed on the end of a platinum wire and held in a Bunsen flame. The only bright radiation was that of the green line, 5359. A doubling of bands occurred when the plates were separated only a few millimetres. With a vacuum-tube radiation, another component was found with wave-length between the principal and first component.

1. Standard Component, Intensity 1.

2. $+1.0 \times 10^{-8}$ mm., " 3/4

3. -0.4 " " 1/4

Hydrogen. By the kindness of Dr. Parsons I used one of his tubes containing hydrogen which was specially pure, the pressure being 1 mm. The red line easily breaks up into three components one on each side of the brightest component.

1. Standard Component, Intensity. 1

2. $+0.6 \times 10^{-8}$ mm., " 1/4

3. -0.2×10 " " 1/8

The green line is very complex, the components are so numerous that observations are very difficult.

The changes in the components due to changes in pressure, size of capillary, capacity in circuit which were studied principally with the mercury radiations were in some cases tried with the other radiations considered and the results were in general the same. The above results with respect to the relative wave-length and intensity of the components under the conditions specified are collected in the following table together with the results of Michelson, and Fabry and Perot upon the same radiations obtained in vacuum-tubes. Michelson's values are taken from the curves given in his paper. His method does not allow the determination as to whether the components have longer or shorter wave-lengths than the standard. The second list of values for the components of the mercury line, λ = 5461, obtained by Fabry and Perot are taken from a paper by *Zeeman.

After the many long and tedious observations together with the study and elimination of the errors which may enter into the results due to imperfect adjustments of the apparatus, the author regrets that he is unable to present a more detailed account of the variations that occur in these component radiations or satellites as they have been called. The changes occur so suddenly on the least change of the surrounding conditions and sometimes even when no changes

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* Astrophys. Journ. 1[illegible], [illegible], [illegible].

[illegible]		[illegible]		[illegible]	
[illegible]	Intensity.	[illegible] x 10[illegible]	[illegible]	[illegible] x10[illegible]	[illegible]
[illegible], λ [illegible]					
1. [illegible] Compt.	1	[illegible]	1	[illegible]	[illegible]
[illegible]	1/10	[illegible]	1/[illegible]	[illegible] - [illegible]	[illegible]
[illegible] 1.[illegible]	1/[illegible]	[illegible] + [illegible].1	1/[illegible]	[illegible] - [illegible].9	1/[illegible]
[illegible].7	1/10	II		[illegible] - 0.[illegible]	1
[illegible]		1. Std. Compt.	1	[illegible]	1/[illegible]
		2. -2.[illegible]	[illegible]/2	6 + [illegible]	1/[illegible]
		3. -0.[illegible]	1/[illegible]		
		4. -0.5	1/[illegible]		
		5. +0.1	1/2		
		[illegible] +0.[illegible]	1/[illegible]		
		7. +1.[illegible]	1/[illegible]		
Mercury, λ = [illegible]					
1. [illegible]	1			1. [illegible] Compt.	1
[illegible].7	1/1[illegible]			2. - [illegible]	1/[illegible]
[illegible]				3. [illegible]	[illegible]
[illegible], λ [illegible]					
[illegible]		[illegible]		1. [illegible]	[illegible]
				[illegible]	1/[illegible]
[illegible], λ [illegible]					
[illegible]	[illegible]	1. [illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1/[illegible]	[illegible]	[illegible]	[illegible]	1/[illegible]
				[illegible]	1/[illegible]
				[illegible]	[illegible]

[illegible]		[illegible]		[illegible]	
[illegible]	Intensity.	[illegible] x [illegible]	[illegible]	[illegible] x [illegible]	[illegible]
Cadmium, λ = [illegible]					
1. [illegible]	1	[illegible]	1	[illegible]	1
[illegible]	1/[illegible]	[illegible]	1/[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	1/[illegible]
[illegible] λ = [illegible]					
[illegible]	1	1. [illegible]	1	1. [illegible]	1
[illegible]	1/[illegible]	2. [illegible] 1.1	1/[illegible]	2. +1.0	3/[illegible]
[illegible] 1.[illegible]	[illegible]	3. +0.[illegible]	[illegible]	3. +0.[illegible]	1/[illegible]
[illegible]	1/8				
[illegible] λ = [illegible]					
1. [illegible] Compt.	1			1. [illegible] Compt.	[illegible]
[illegible]	[illegible]			2. +0.[illegible]	[illegible]
				3. +0.[illegible]	[illegible]

different to the observer were introduced, that only qualitative results of a very general nature can be expressed.

During the observations upon the sharp interference-fringes due to the mercury green radiation in the two cases, when the components were visible as exemplified by the photograph given by Fabry and Perot as referred to above, and when with the same separation of the silvered plates, the components were not present as exemplified by Fig. 13, Plate II, the question arose, - has the change in the conditions given birth to one or more satellites? The sharpness of the fringes in both cases, the unequal change in the intensity of the various components under variable conditions, as is shown when the capillary of a vacuum-tube is heated, and in the fact that the results given in the above table upon the distances between the components are in poor agreement which is probably due to the different circumstances surrounding the radiation, all point to the possibility of the production of satellites. It must not be forgotten, however, that at the separation of the plates necessary to show the presence of the components the interference-fringes are very close to one another so that it is impossible in this method for an interference-fringe due to the birth of a satellite to appear without overlapping some part of the in-

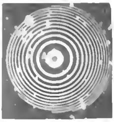
interference-fringes of t[illegible] ts [illegible] pro-
duce a new distribution of light in the interference-pattern which would naturally lead to different results.

The investigations of the variations in the wave-length and intensity of radiations separated by the grating on account of variation in pressure, electrical condition of the discharge, and the chemical nature of the dielectric surrounding the luminous substance, is at present a very fruitful field. For these changes in these widely separated lines lend themselves to measurement. It is hoped that a method will be found which will more readily show and give measurements of the many changes that occur in radiations whose wave-lengths and hence their frequencies do not differ greatly, so that ultimately some knowledge as to the mechanics of the systems of moving electrons constituting the atom whose periods differ by small amounts relative to those obtainable at present may be obtained. A step in this direction has been made by Lummer. The reproductions in the Ann. d. Phys., 10, p. 173, 1903, show excellently the complicated structure of these bright radiations. The method proposed above, employing longer plates is worthy of a fair trial.

My heartiest thanks are due to all my professors and instructors in physics in this University, especially Professor Ames and Professor Wood, and also to my fellow students whose kind assistance in word and deed has greatly facilitated these experiments.

Physical Laboratory,
Johns Hopkins University.

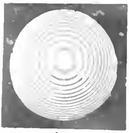
Plate I.



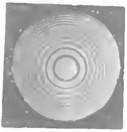
1.

2.

3 4. 5.

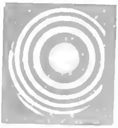


6.



7

8.



9.

10.

11.

12.

Interference Fringes under Various Conditions

Plate II

13.

14.

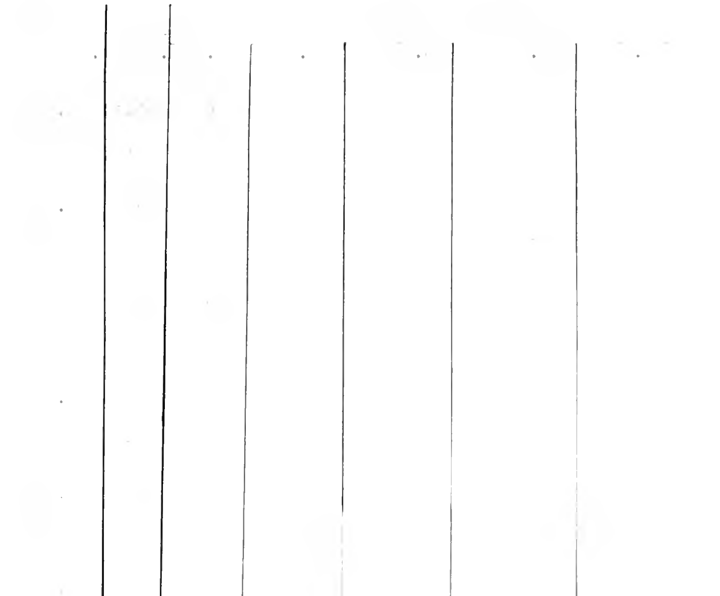
15.

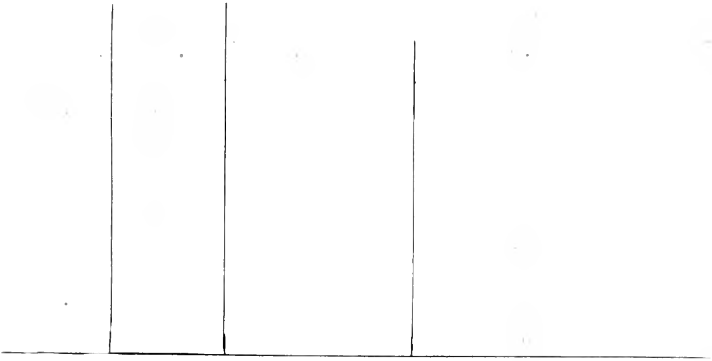
16.

Figs. 13 and 16 green [illegible]

Figs. 14 and 15, sodium lines.

60





λ

λ

spark

λ λ

Plate III

Spectrum of
Magnesium Arc
obtained in a Vacuum.

1.

λ4481

Spectrum showing line λ4481
only at the cathode.

λ4481

2.